Science of Climate Change - Why Net Zero 2050?

CALL – Canmore
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https://manzwaterinfo.ca/climate-change

Climate change is real, it is happening and it is important.

Climate changes today are still caused by <u>natural forces</u> such as changes in Earth's orbit and volcanoes; but, the immediate causes are <u>human activities</u> – release of greenhouse gases and changes in land use.

While natural forces caused very significant climate changes in the past, with catastrophic impacts to all life on Earth, human activities now promise to cause equally significant climate change with equally serious impacts.

The difference is: Humans can prevent significant climate change from happening at all.

Brief History of the Study and Reporting of the Science of Climate Change

(https://en.wikipedia.org/wiki/History_of_climate_change_science#:~:text=The%20history%20of%20the%20scientific,natural%20greenhouse%20effect%20first%20identified and https://en.wikipedia.org/wiki/Milankovitch_cycles)

- **Joseph Fourier (1827): Proposed that the Earth was warmed by the atmosphere 'trapping' heat similar to a greenhouse – the so-called 'greenhouse effect'.**

(Beginning of science. Curiosity based research.)

- **Louis Agassiz (1837): Development of the 'Ice Age' theory of climate change.**

(Climate change was discovered!)

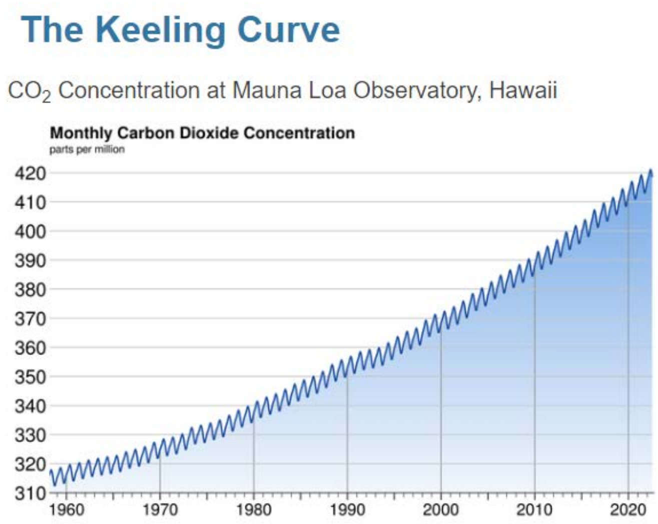
- **John Tyndall (1859) : Described the physics behind the greenhouse effect by identifying the various gases in the atmosphere and how they would transmit short wave radiation and absorb and reemit infrared radiation back to the Earth's surface and outer space.**

- **Svante Arrhenius (1896): Established the importance of the role of carbon dioxide in Earth's atmosphere as the principal gas that was responsible for the greenhouse effect.**

- **Milutin Melankovic (1920's): Identified the correlation between the cyclical variations of Earth's orbit and the tilting of its axis to the occurrence and disappearance of the ice ages.**

History (cont'd)

- **Charles Keeling, Scripps CO2 Program(1961) https://scrippsco2.ucsd.edu/ : Concern over the discharge of carbon dioxide into the atmosphere and the development of instrumentation with which to measure carbon dioxide in the atmosphere lead to the establishment of a base on Mauna Loa, Hawaii that continuously monitored the concentration of carbon dioxide in the atmosphere. This ultimately lead to the development of the 'Keeling Curve' shown below:**



- **Syukuro Manabe and Richard Wetherald (1967): First detailed calculation of the greenhouse effect using a computer model.**

History cont'd

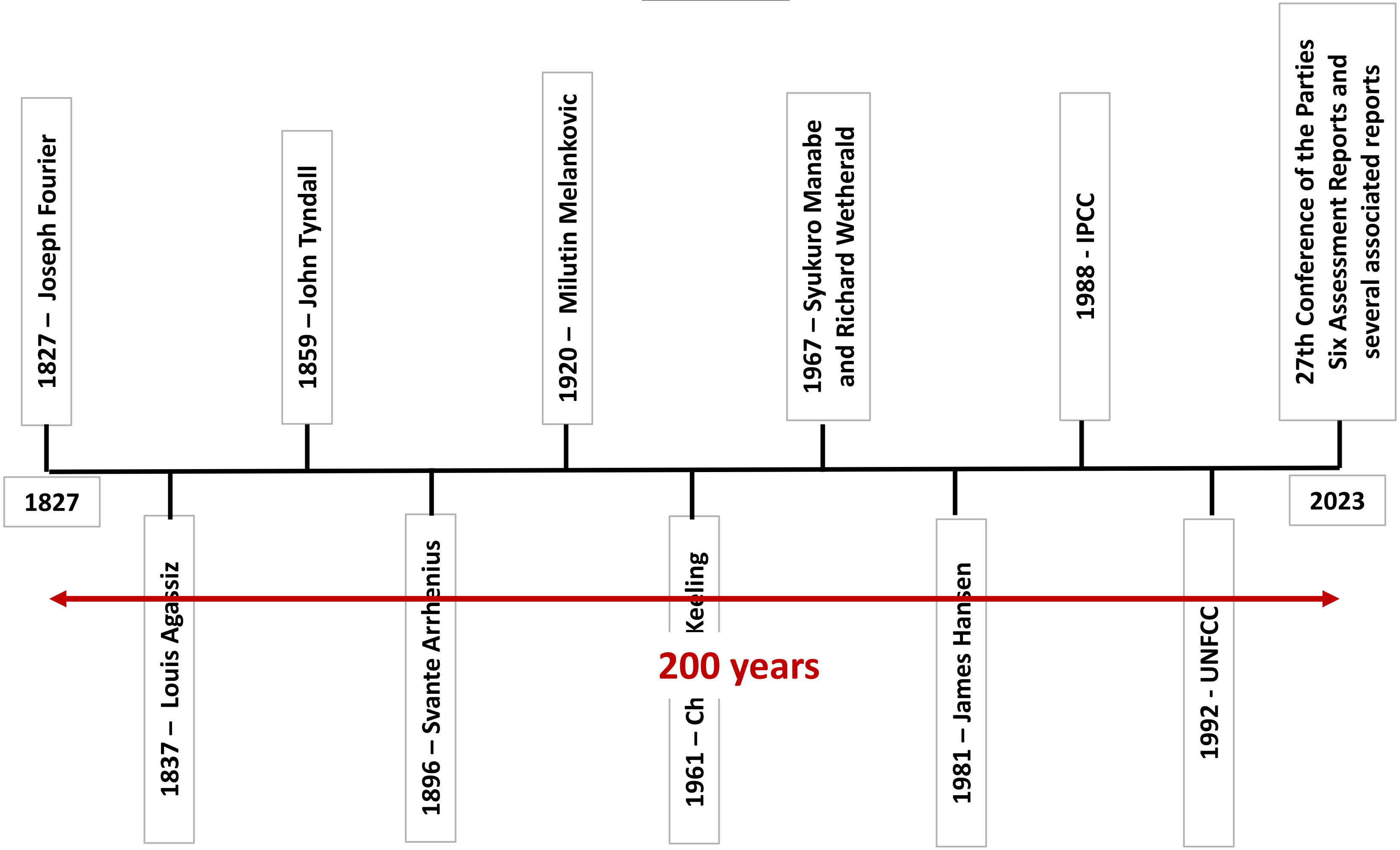
- James Hansen (1981): Published a study with others titled, Climate impact of increasing atmospheric carbon dioxide, (https://pubs.giss.nasa.gov/abs/ha04600x.html) which identified the significance of global warming on climate change. These concerns were reported to the U. S. Congress in 1988.

- Intergovernmental Panel on Climate Change, IPCC (1988) https://www.ipcc.ch/about/history/ : Created by the United Nations Environmental Program and the World Meteorological Organization to assess the science related to climate change and report this to world governments and later the UNFCCC. There are six IPCC Assessment Reports – most recent the AR6 published in 2021, 2022 and 2023.

- United Nations Framework Convention on Climate Change, UNFCCC (1992) https://unfccc.int/ : Tasked with supporting the global response to the threat of climate change. As part of its mandate the UNFCCC hosts the Conference of the Parties (COP) to communicate the reports of the IPCC to countries and establish global and country response. The most recent is COP28 in UAE. (Canada – Maurice Strong - played a significant role in the founding of the UNFCC.)

Brief History of the Study and Reporting of the Science of Climate Change

<u>Timeline</u>



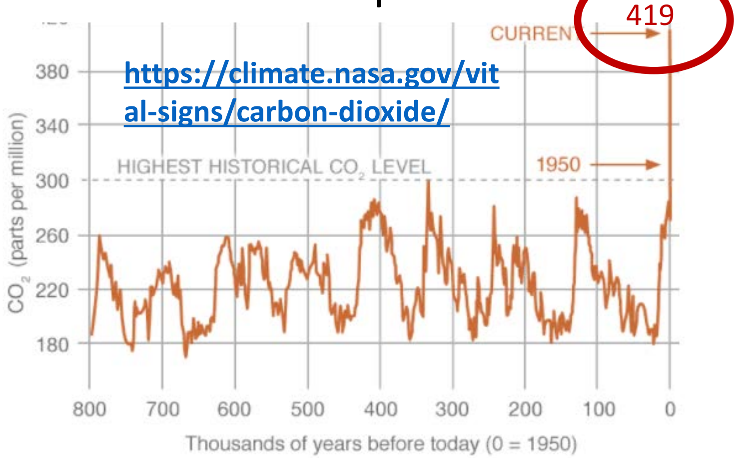
Communication of the threat of climate change to world populations has proven a significant challenge. The IPCC and former U. S. Vice President Al Gore were awarded the 2007 Nobel Peace Price for their efforts.
https://www.nobelprize.org/prizes/peace/2007/summary/

Reaction to these warnings has been less than one would have hoped (similar to Covid 19).

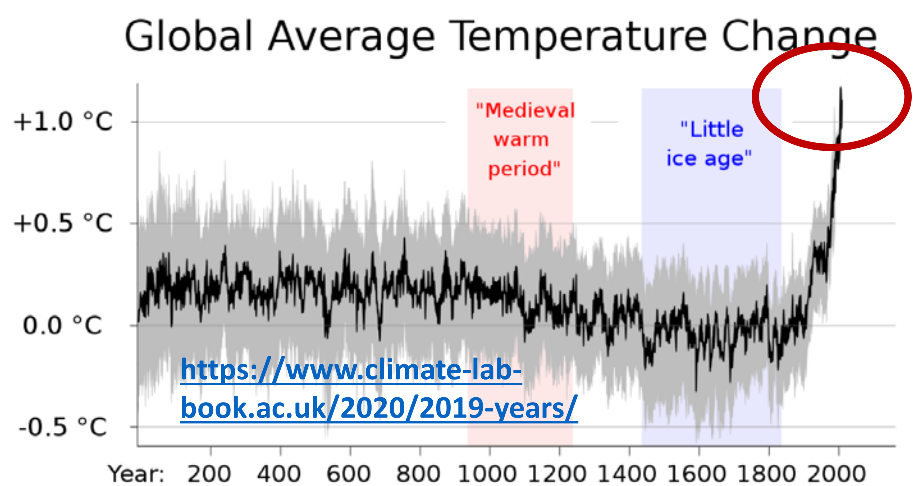
Is the climate change we are presently experiencing 'Normal' for Earth?

To answer this question we must defer to the study of '<u>paleoclimatology</u>', such as information on past climate gained from the ice cores drilled into the ice fields of Greenland and Antarctica which provide information on temperature, precipitation, concentration of greenhouse gases, aerosols and other information. Several other proxy methods for estimating age, temperature and precipitation are also used.

Proxy measurements of CO2 in the atmosphere.



https://climate.nasa.gov/vital-signs/carbon-dioxide/



https://www.climate-lab-book.ac.uk/2020/2019-years/

Not 'Normal'!

Why is human caused climate change important?

1. The IPCC AR6 WGII (Impacts, Adaptation and Vulnerability) clearly describes the consequences of not limiting temperature increase to 1.5 °C by 2021 and they are not desirable from the perspective of life on Earth. (https://www.ipcc.ch/working-group/wg2/)

2. Changes in the physical environment affect the entire biological community including humans.

Humans may cope but biodiversity is threatened.

https://www.conservation.org/blog/in-global-climate-change-fight-half-a-degree-could-make-all-the-difference?gclid=Cj0KCQiAgribBhDkARIsAASA5bu4bZbTlGEa88ONFzUqJMvhH3QsaEgd8fvb9HjRwA2mtNiV-RRGQK4aAmanEALw_wcB and https://www.science.org/doi/full/10.1126/sciadv.aau9981

Humans appear to be the cause for the 6th extinction of life on Earth!

The International Union for the Conservation of Nature https://www.iucnredlist.org/ has recently updated its Red List of Threatened Species. One in four species are at risk of extinction.

Species assessed are:

1. **Amphibians 40% of the species are a risk.**
2. **Conifers 34%.**
3. **Reef corals 33%.**
4. **Sharks and rays 31%.**
5. **Selected crustaceans (lobsters and freshwater crabs, crayfishes and shrimps).**
6. **Mammals 25%.**
7. **Birds 14%.**

Most life is similarly threatened.

Observation and impacts of recent climate change.

(https://img1.wsimg.com/blobby/go/db3f6246-68ba-44c1-9dc1-5cb368acf5a3/downloads/Chapter%2016%20Observations%20and%20Impacts%20of%20Recent%20.pdf?ver=1667865135599)

1. **Increase in greenhouse gas and temperature.**
2. **Ocean acidification.**
3. **Arctic:**
   1. **Shrinking sea ice.**
   2. **Loss of permafrost.**
   3. **Loss and change of wildlife habitat.**
   4. **Impaired transportation.**
   5. **Resurgence of territorial claims.**
   6. **Release of methane and GHG's.**
   7. **Loss of glaciers.**
4. **Greenland – loss of ice field and glaciers.**
5. **Antarctica:**
   1. **Break up of ice shelves.**
   2. **Loss of ice mass.**
   3. **Loss and change of wildlife habitat.**

6. **Oceans – warming, sea level increase, disturbance and possible weakening of the Atlantic Meridional Overturning Current.**
7. **Loss of coral reefs.**
8. **Change in thermal habitat of oceans and lakes.**
9. **Droughts more frequent and widespread.**
10. **Desertification expanding.**
11. **Wildfires more frequent and widespread.**
12. **Tropical cyclones more frequent and stronger.**
13. **Glaciers loss of mass.**
14. **Habitat change – challenging biodiversity.**
15. **Intensification of extreme weather including:**
    1. **Heat dome effects.**
    2. **More frequent and stronger atmospheric rivers.**
    3. **Increasing major snowstorms.**

16. **Human health including:**
    1. **Heat and hot weather.**
    2. **Disease.**
    3. **Hunger.**
    4. **Loss of home.**
    5. **Stress.**
17. **Social impacts including:**
    1. **Poverty**
    2. **Migration.**
    3. **War.**

Extreme weather events in 2022 that have been attributed in part to climate change include:

1. **Heatwave, drought and wildfires in Europe.**
2. **Heatwave, drought and wildfires in North America.**
3. **Flooding in the United States.**
4. **Heatwave, drought and wildfires in China.**
5. **Flooding in China.**
6. **Drought in Africa.**
7. **Heatwave and drought in India and Pakistan.**
8. **Flooding in Pakistan.**
9. **Flooding in Brazil.**
10. **Flooding in India and Bangladesh.**
11. **Flooding in South Korea.**
12. **Flooding in Australia.**

14. **Drought in Chile.**
15. **Heatwave in Japan.**
16. **Hurricane Fiona – Puerto Rico and Canada.**
17. **Hurricane Ian – Cuba, Florida, South Carolina and North Carolina.**
18. **Typhoon Nanmadol – Philippines and Japan.**
19. **Super typhoon Noru – Philippines and Viet Nam.**
20. **Nigeria flooding.**
21. **Arctic warming.**
22. **Antarctic warming.**

All of Earth is affected! Happening again in 2023.

On what basis do we attribute extreme weather events to climate change?

The field of science is known as 'extreme weather attribution'. The fifth annual update on extreme weather attribution is published by the newsletter, Carbon Brief, that may be found in

https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world/?utm_campaign=Daily%20Briefing&utm_content=20220805&utm_medium=email&utm_source=Revue%20newsletter

This study reports that human-caused climate change made:

- **93% of 152 extreme heat events more likely or more severe.**
- **56% of flooding events more likely or more severe.**
- **68% of 81 drought events more likely or more severe.**

The World Weather Attribution initiative (https://www.worldweatherattribution.org/) **was founded to provide robust assessments on the role of climate change in the aftermath of the event. Several of the extreme weather events listed for 2022 and others that have occurred or presently occurring in 2023 have been attributed to human-caused climate change.**

What climate changes must we adapt to?

(Adaption)

How do we stop human caused climate change?

(Mitigation)

What is the Science of Climate Change?

Weather vs Climate

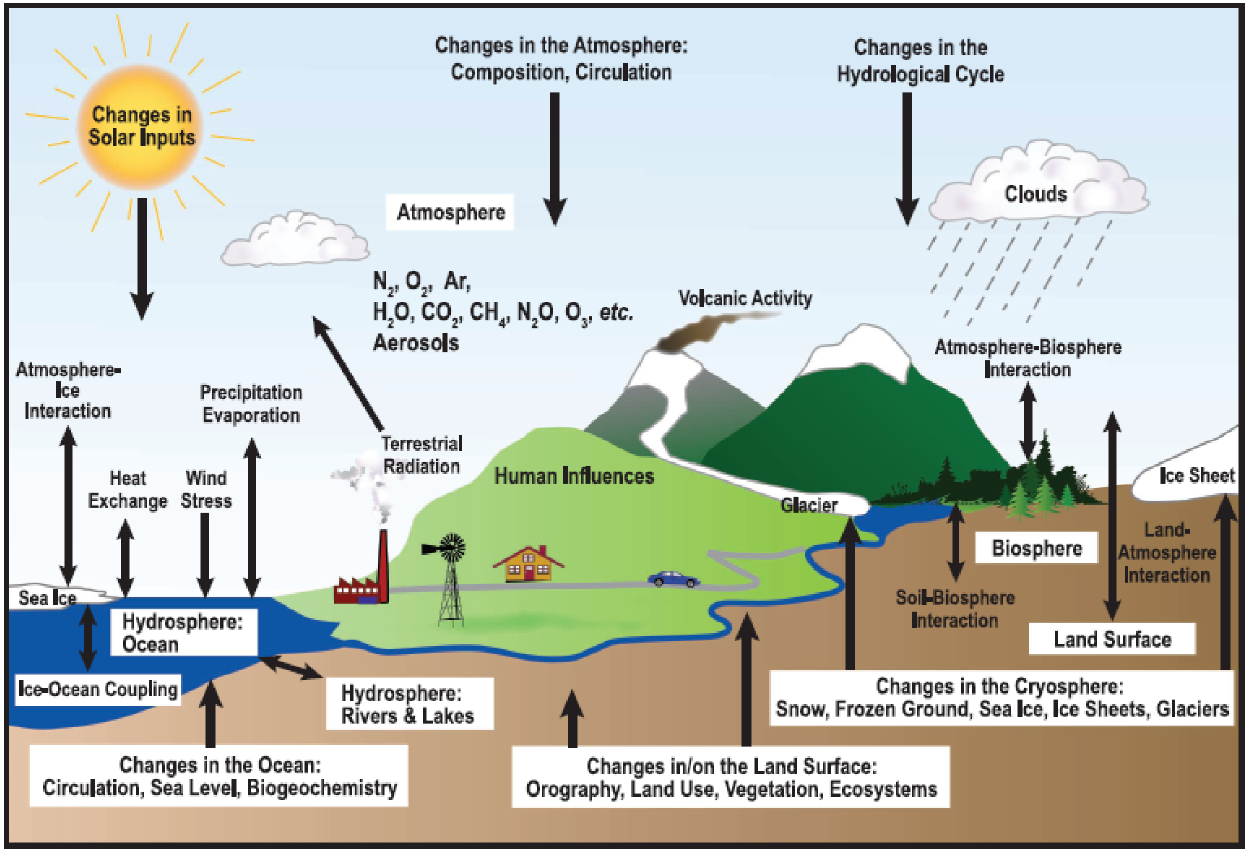
Weather is NOT climate. Weather is a real-time reflection of climate.

Weather happens day to day (moment to moment) – best forecast is for no more than 10 days.   Weather may appear to vary quite significantly but these variations are consistent with a region's climate.

Climate is a long-term average of weather typically including precipitation and average temperature – averaged over a season (several months), years, decades or much longer.   Climate is used to describe large regions that are geographically homogenous.

The climate of a region, short and long term, will not only determine the physical nature of the environment but also the characteristics of its biosphere – plants and animals.

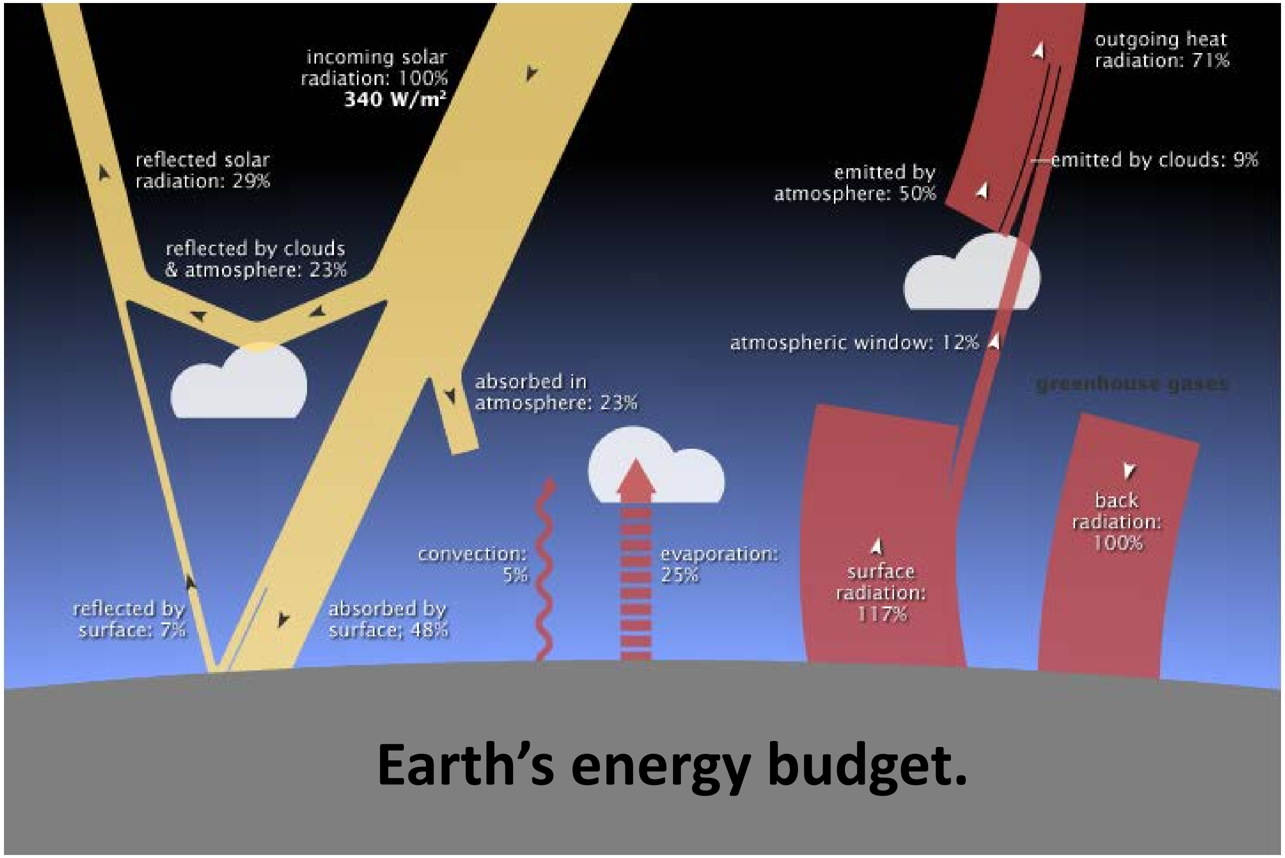
If the climate of a region is known, weather patterns can often be inferred.



FAQ 1.2, Figure 1. *Schematic view of the components of the climate system, their processes and interactions.*

There are many factors that affect climate – too many to consider without a well thought out strategy.

Must take a 'systems approach' to the study starting with the 'Energy Budget'.



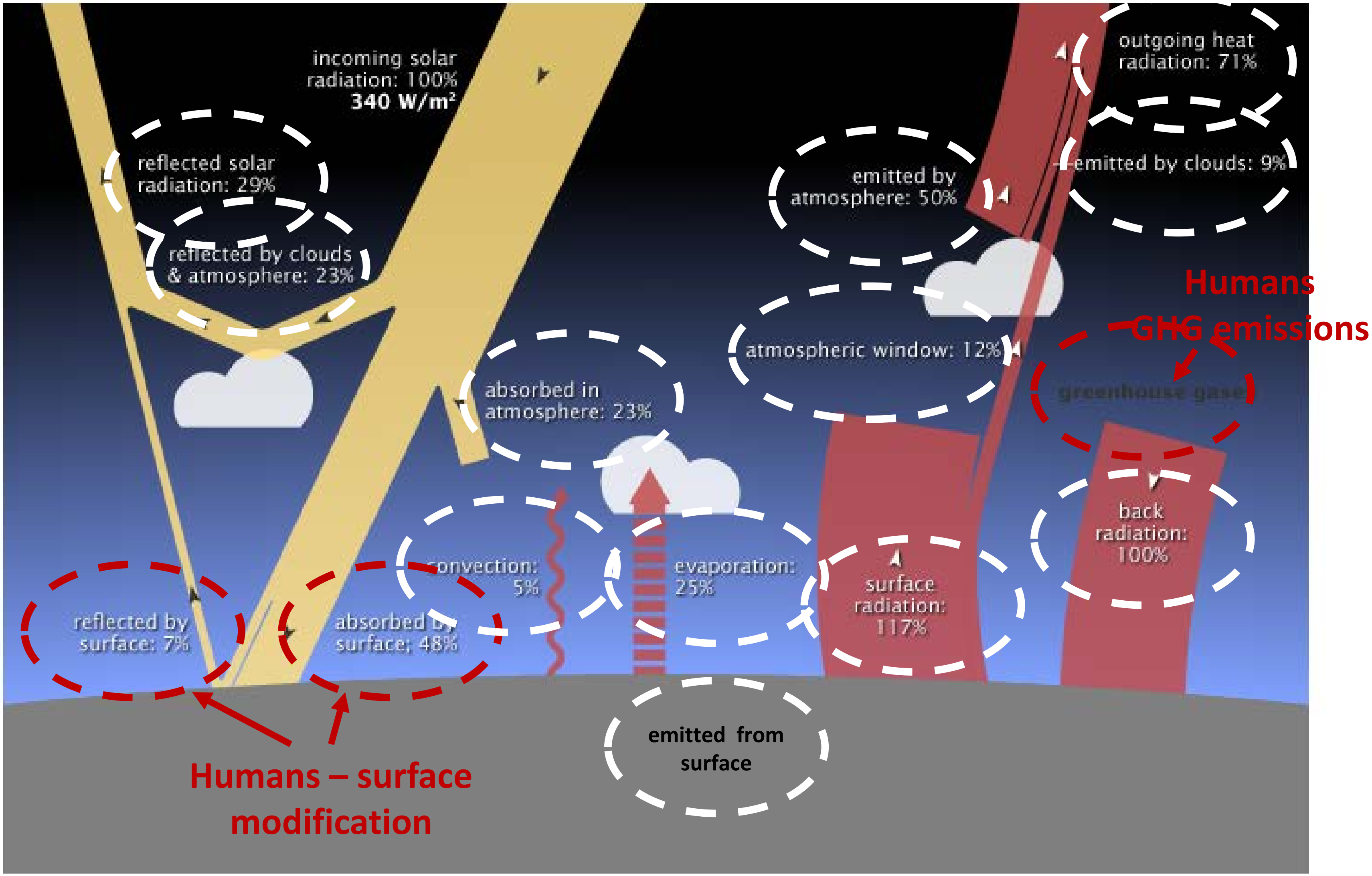
Earth's energy budget.

https://earthobservatory.nasa.gov/features/EnergyBalance

Conservation of energy – amount of solar energy reaching Earth equals the amount of reflected energy and longwave energy (heat radiation) leaving Earth.

This is a stable system – no energy is being stored.

Earth is neither warming nor cooling.



<u>Components of energy budget affected by human activities.</u>

Components circled in dashed red are directly affected.

Components circled in white are indirectly affected.

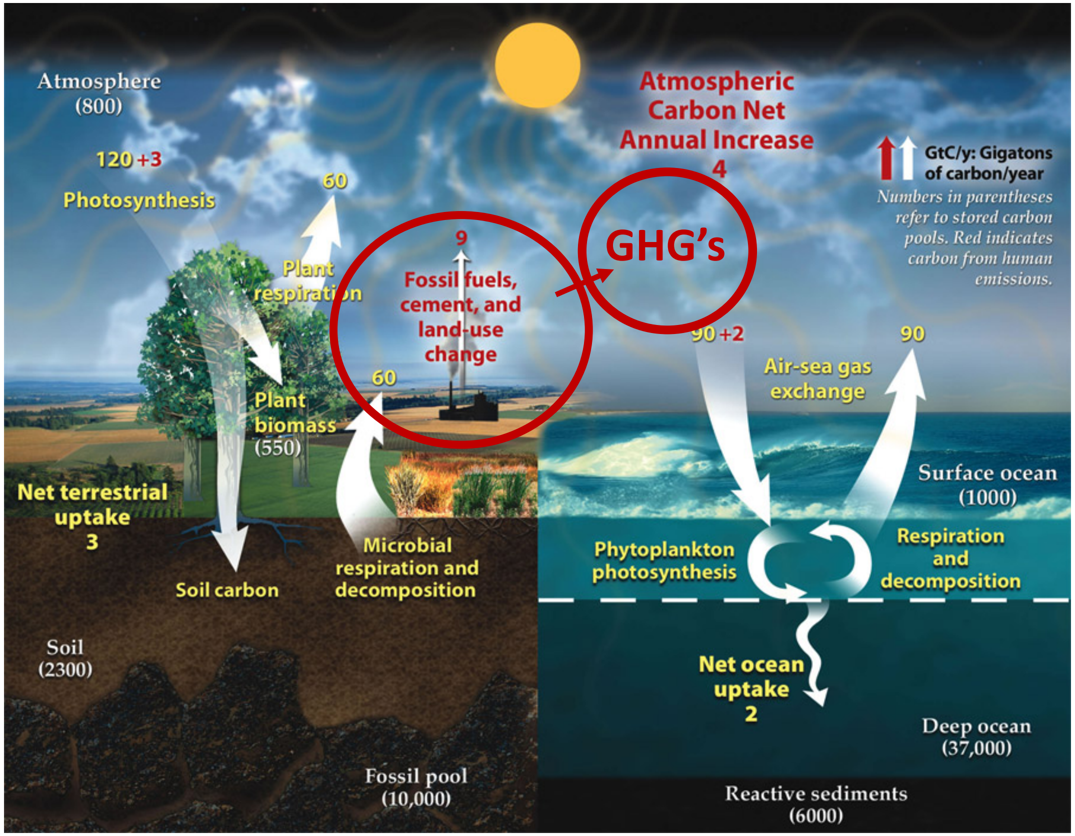
Consider greenhouse gases.

Greenhouse gases, GHG's, are a normal part of the Earth's atmosphere. Human activities are continuously adding GHG's to the atmosphere.

GHG's will persist in the atmosphere for a period of time before they disappear. There are several GHG's and each behaves differently.

The concentration of a GHG in the atmosphere will increase until additions of the GHG to the atmosphere are stopped; or, the processes which cause the GHG to disappear are able to remove the GHG at a greater rate than it is being emitted.

Carbon Cycle



https://www.energy.gov/science/doe-explainsthe-carbon-cycle

All GHG's are important but the most significant is carbon dioxide.

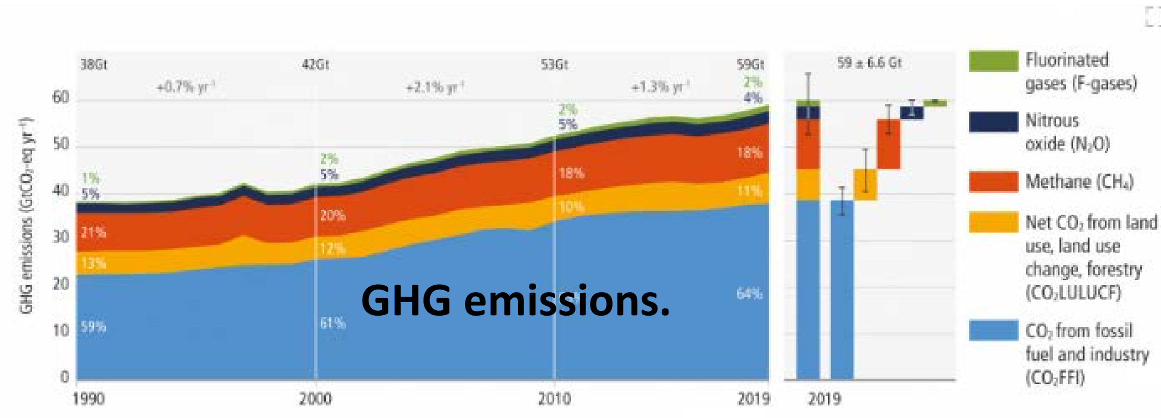
The circulation of carbon to and from the surface of the Earth to the atmosphere is known as the carbon cycle.

Major recent sources of carbon dioxide are fossil fuels, cement production and land use change.

The life of carbon dioxide in the atmosphere varies between 300 and 1000 years.

GHG's of interest are:

- **Carbon dioxide.**
- **Methane.**
- **Nitrous oxide.**
- **Small amounts of others.**



GHG emissions.

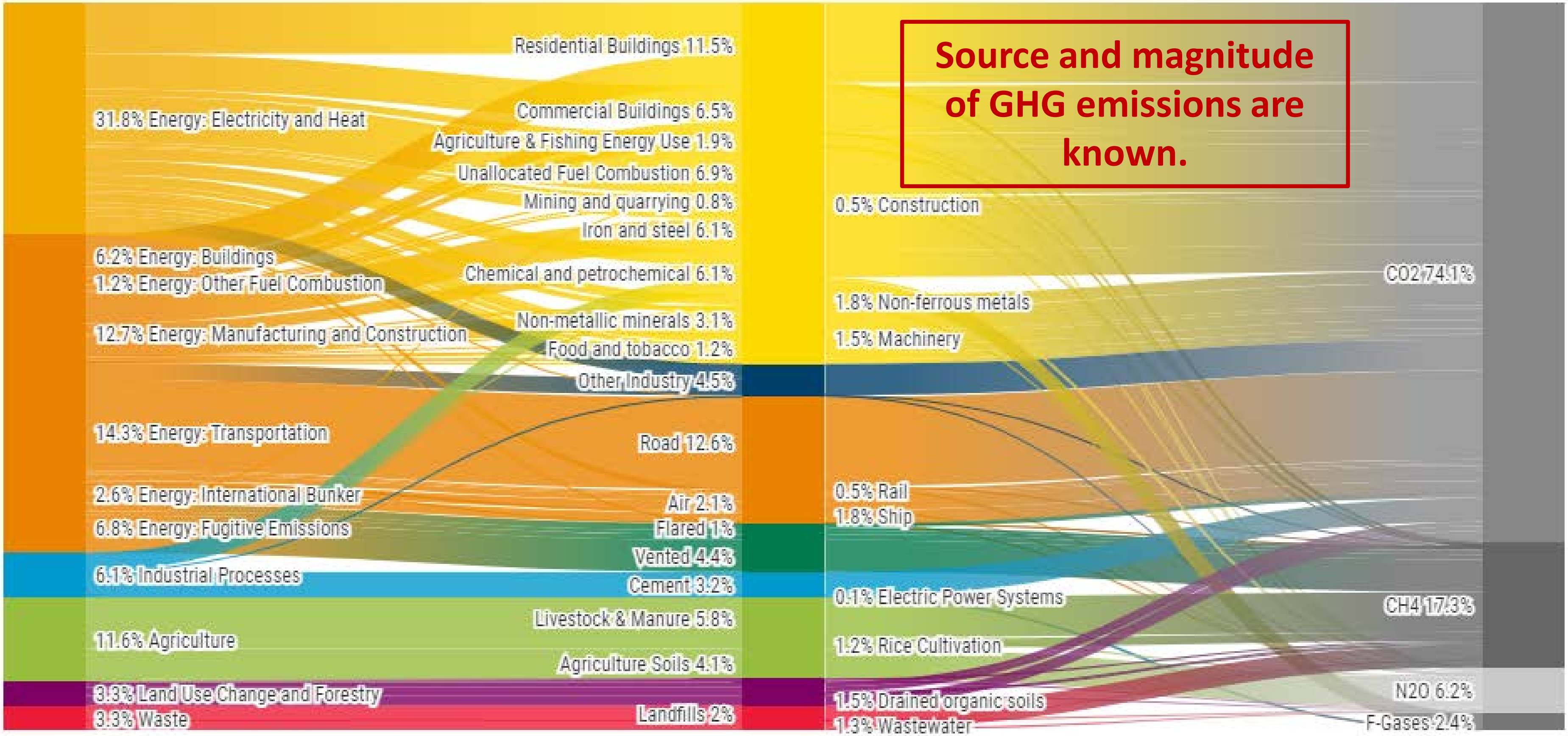
Steadily increasing.

https://climate.nasa.gov/news/2915/the-atmosphere-getting-a-handle-on-carbon-dioxide/#:~:text=Carbon%20dioxide%20is%20a%20different,timescale%20of%20many%20human%20lives

Carbon dioxide: 415.7ppm ± 0.2 = **149% of pre-industrial levels.**
Methane: 1908±2 ppb = **262% of pre-industrial levels.**
Nitrous oxide: 334.5±0.1 ppb = **124% of pre-industrial levels.**

World Greenhouse Gas Emissions in 2019 (Sector | End Use | Gas)

Total: 49.8 GtCO2e

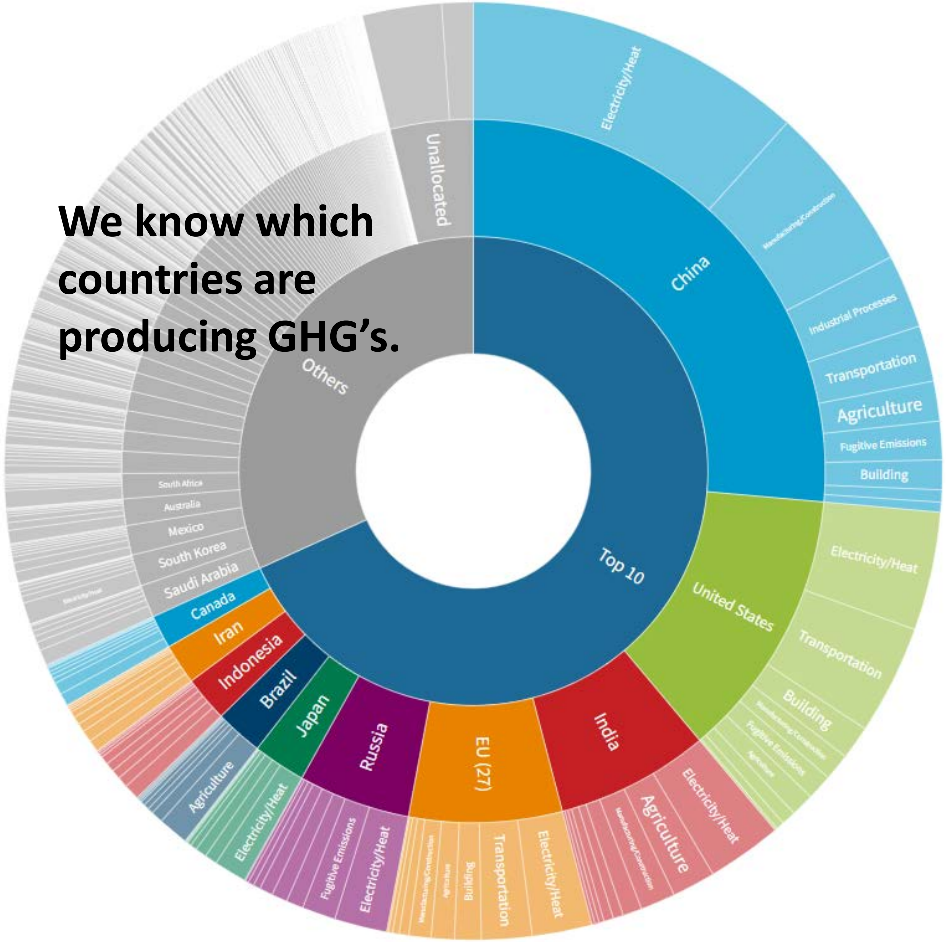


Source: Climate Watch, based on raw data from IEA (2021), GHG Emissions from Fuel Combustion, www.iea.org/statistics; modified by WRI.

WORLD RESOURCES INSTITUTE

https://www.wri.org/data/world-greenhouse-gas-emissions-2019

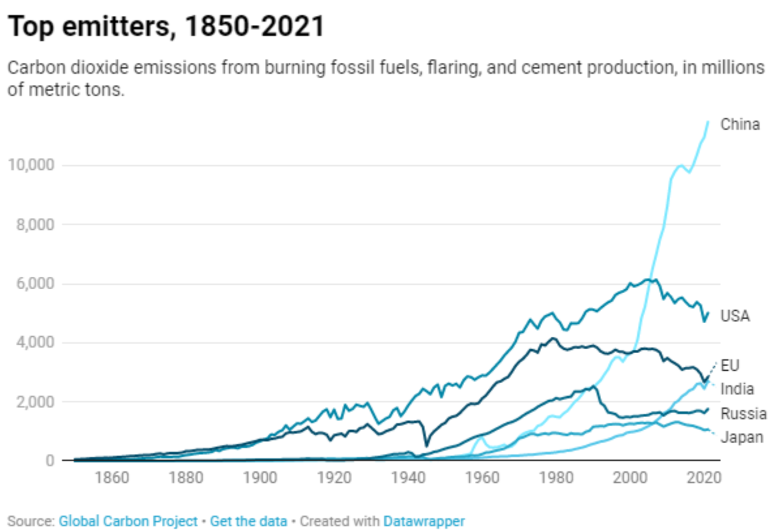
Greenhouse gas emissions by country.

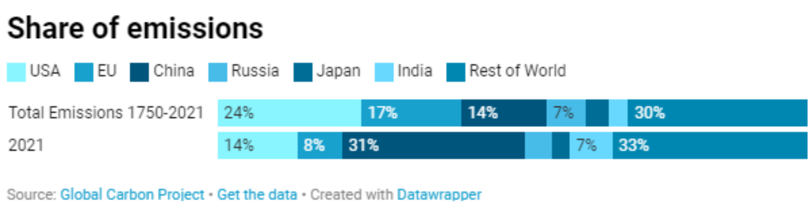


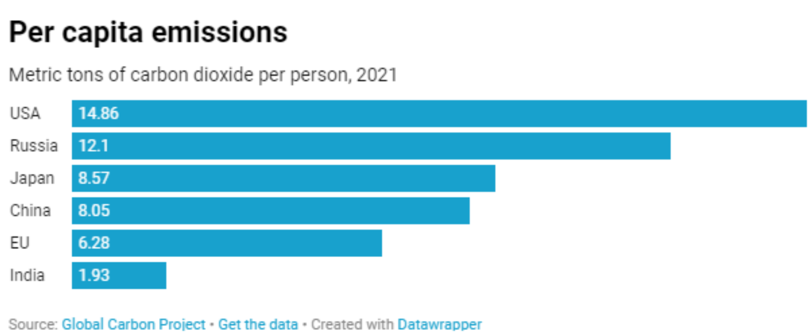
We know which countries are producing GHG's.

https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors

Updated emissions to 2021.







https://www.globalcarbonproject.org/

https://www.technologyreview.com/2022/11/18/1063443/responsible-climate-change-charts/?truid=&utm_source=the_download&utm_medium=email&utm_campaign=the_download.unpaid.engagement&utm_term=&utm_content=11-22-2022&mc_cid=3bd8e0c951&mc_eid=89ad5f9312

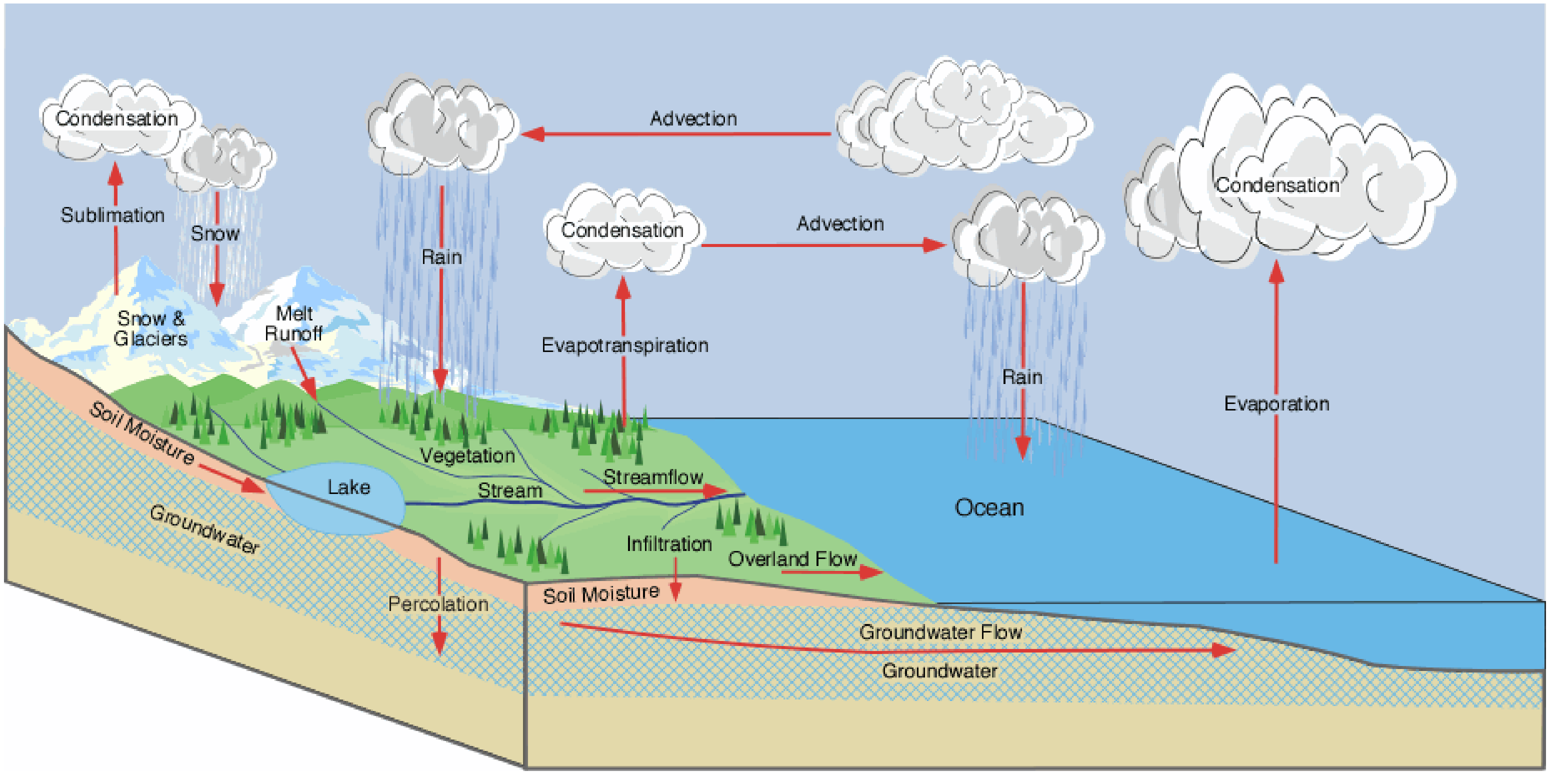
Water Vapour

Water vapour is also a GHG and when it condenses in the atmosphere to form droplets it behaves like an aerosol. Unlike other GHG's, water vapour does not accumulate in the atmosphere. Ultimately, water vapour will return to Earth as a liquid or solid precipitate where it will evaporate, sublimate or transpire to return to the atmosphere as a gas.

The maximum amount of water vapour in the atmosphere is limited by the temperature of the atmosphere. The warmer the atmosphere, the more water vapour it can hold.

The circulation of water is known as the hydrological cycle.

Hydrological Cycle

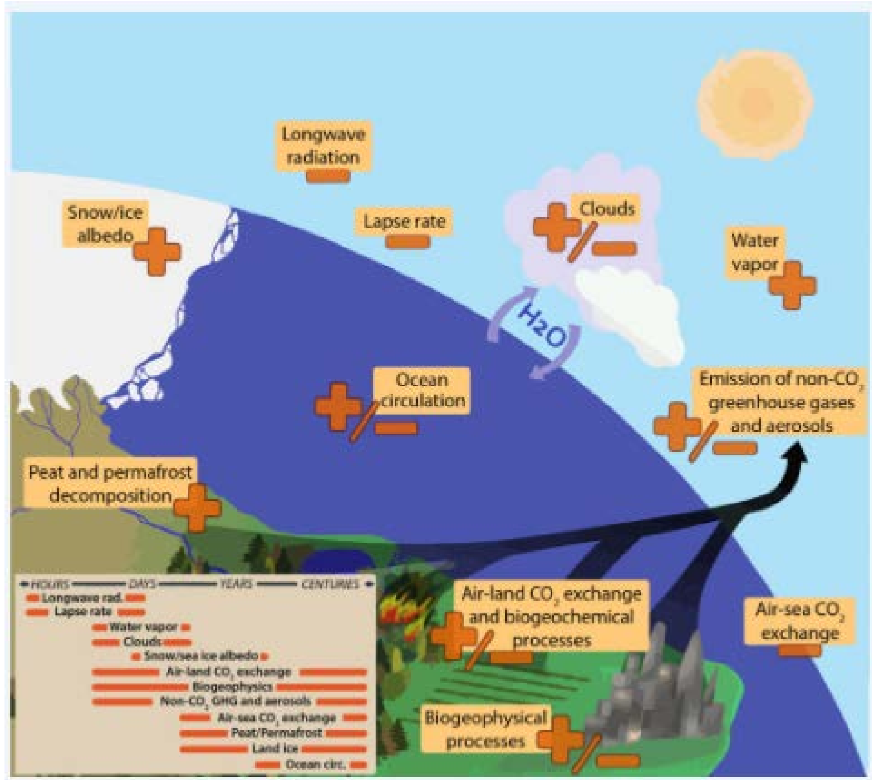


http://www.physicalgeography.net/fundamentals/5c_1.html

Climate models are used to answer the question:

What is the effect of adding GHG's to the atmosphere?

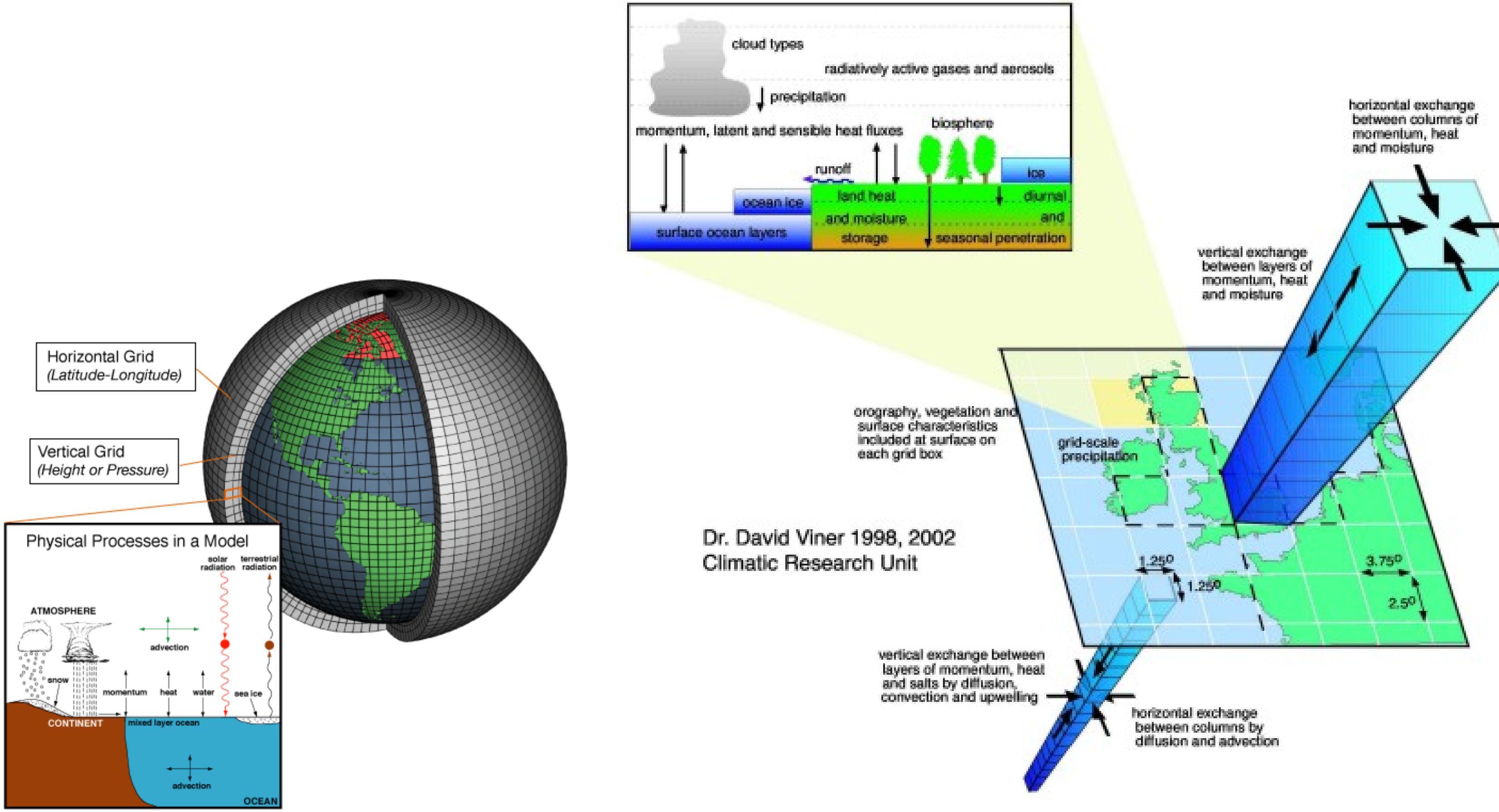
What is being considered?



Subsystems included in climate models.

https://www.ipcc.ch/report/ar5/wg1/

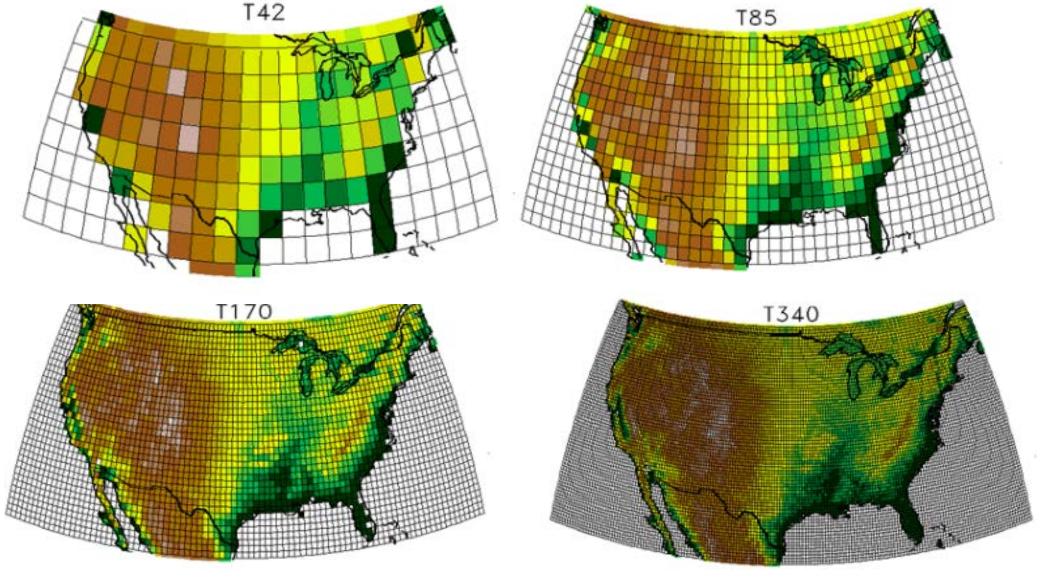
(Climate modelling has come a long way since the 1960's.)



This image shows the concept used in climate models. Each of the thousands of 3-dimensional grid cells can be represented by mathematical equations that describe the materials in it and the way energy moves through it. The advanced equations are based on the fundamental laws of physics, fluid motion, and chemistry. To "run" a model, scientists specify the climate forcing (for instance, setting variables to represent the amount of greenhouse gases in the atmosphere) and have powerful computers solve the equations in each cell. Results from each grid cell are passed to neighboring cells, and the equations are solved again. Repeating the process through many time steps represents the passage of time. Image source: NOAA.

Modelling concept used in atmospheric-ocean general circulation models, AOGCM's and earth system models, ESM's. https://www.climate.gov/maps-data/primer/climate-models and

https://soccom.princeton.edu/content/what-earth-system-model-esm



Resolution:

- T42 – 200 x 300 km
- T85 – 100 x 150 km
- T170 and T340 – regional models much finer resolution – interpolation techniques.
- **Today – 87.5 km x 87.5 km and 30 km x 30 km**

Comparison of grids used in climate models since they were first being developed for use in IPCC Assessment Report 1 to Assessment Report 5. https://scied.ucar.edu/longcontent/climate-modeling

https://eo.ucar.edu/staff/rrussell/climate/modeling/climate_model_resolution.html

Smaller the cells the more precise the simulation.

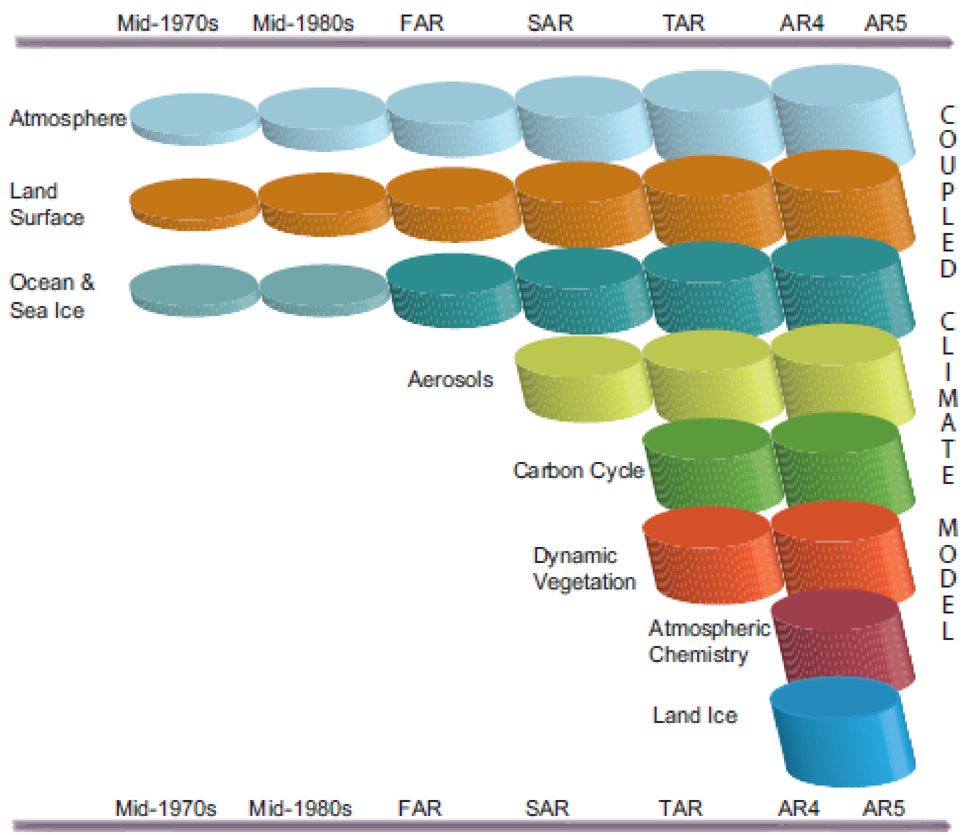


Figure 1.13 | The development of climate models over the last 35 years showing how the different components were coupled into comprehensive climate models over time. In each aspect (e.g., the atmosphere, which comprises a wide range of atmospheric processes) the complexity and range of processes has increased over time (illustrated by growing cylinders). Note that during the same time the horizontal and vertical resolution has increased considerably e.g., for spectral models from T21L9 (roughly 500 km horizontal resolution and 9 vertical levels) in the 1970s to T95L95 (roughly 100 km horizontal resolution and 95 vertical levels) at present, and that now ensembles with at least three independent experiments can be considered as standard.

Development of climate change models. https://www.ipcc.ch/report/ar5/wg1/

Models used in AR6 are even more complex including such things as deforestation due to wildfires and melting permafrost.

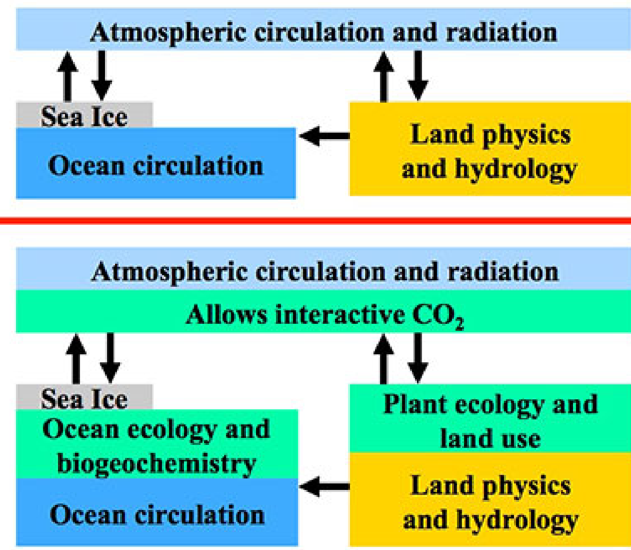
An Earth System Model (ESM) closes the carbon cycle

Climate Model

AOGCM

Earth System Model

Everything considered.



SOCCOM scientists are studying several different ESM simulations run by GFDL as well as other modeling centers around the world. Model performance is evaluated with the help of standardized, observationally-based metrics.

Comparison between a climate model and an earth system model.

https://soccom.princeton.edu/content/what-earth-system-model-esm

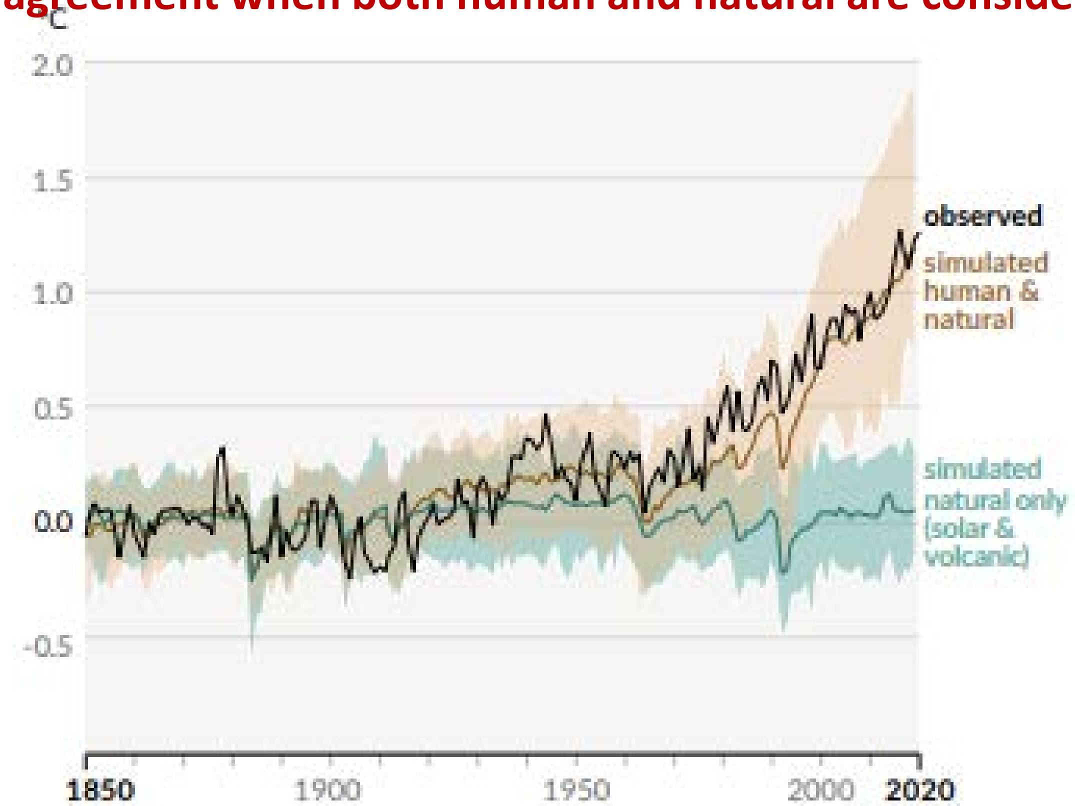
Who are developing models?

More than 50 modelling groups worldwide.

There are dozens of models of several types. The models are evaluated using what is known as the 'Coupled Model Intercomparison Project'. The most recent one is CMIP6 https://pcmdi.llnl.gov/CMIP6/ . An overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization may be found in https://gmd.copernicus.org/articles/9/1937/2016/gmd-9-1937-2016.html .

Comparison of modelling results to observations.

Very good agreement when both human and natural are considered together!



Change in global surface temperature (annual average) as observed and simulated using human and natural factors and only natural factors (both 1850-2020) °C.

https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

Climate models are used to determine how the climate would change in the response to changes to any or all of the processes.

Of particular interest is the climate response to changes in concentrations of greenhouse gases in the atmosphere, in particular, carbon dioxide, methane and nitrous oxide.

A standard 'set' of concentrations, emissions and radiative forcings of the GHG's and all other input data was developed for use by the numerous models that were part of the IPCC assessments – CMIP5 and CMIP6.

AOESM's and ESM's require super-computers to run – expensive. A variety of simpler models have been developed, that require much less computational resources to run. These are used to perform detailed studies of the impact on climate change of numerous scenarios of interest. (Models are calibrated using the full AOESM's.)

The apparent success of the models suggests that the 'science' is understood well enough to be able to use the models to forecast adaptation needs and mitigation strategies.

The consensus among climate scientists (more than 99%) is that the 'science is very good' – and conclusions irrefutable. (https://news.cornell.edu/stories/2021/10/more-999-studies-agree-humans-caused-climate-change)

Scientists believe they have the tools to estimate with confidence what the effects of continuous emissions of GHG's into the atmosphere will be.

How is this done?

<u>Five estimates of GHG emissions</u> were developed by many scientists of all disciplines for each of the years from 2015 to the year 2100. (See: https://skepticalscience.com/rcp.php .)

These 'estimates' were originally named 'representative concentrations pathways' and now the term 'shared socioeconomic pathways' is used. The pathways are also known as scenarios.

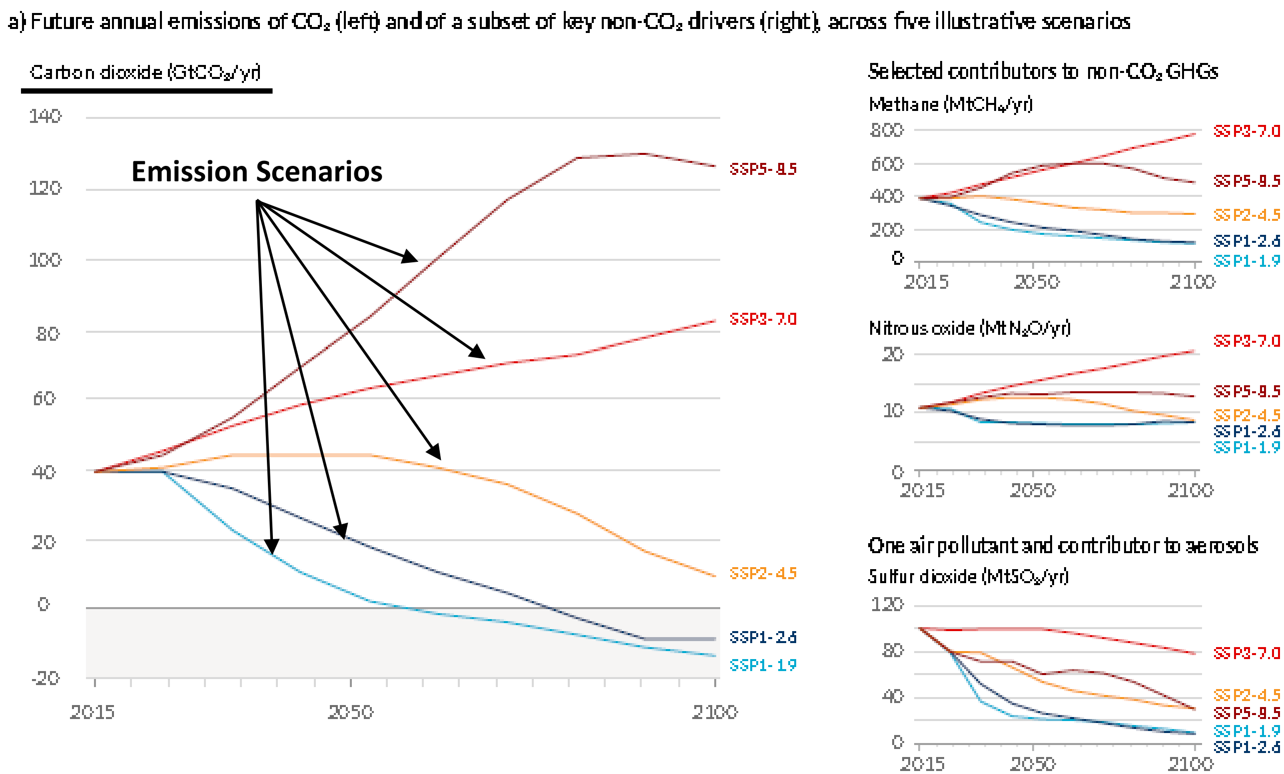
"Modelling results for each of the scenarios provide a basis for assessing the risk of crossing identifiable thresholds in both physical change and impacts on biological and human systems"

These scenarios were used by all climate models to predict the effects of increases in GHG's on climate.

Ultimately, the results of the modelling exercises provide a guideline for developing GHG management strategies going forward.

The next slide shows the five emission scenarios that were developed for carbon dioxide, methane, nitrous oxide and sulfur dioxide, an aerosol.

Future emissions cause future additional warming, with total warming dominated by past and future CO_2 emissions



Summary for policy makers. https://www.ipcc.ch/report/ar6/wg1/

This table summarizes the modelling results. It shows how the global temperature would change with emissions following each of the five pathways or scenarios.

	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

AR6 Scenarios. https://www.ipcc.ch/report/ar6/wg1/

For example: Consider scenario SSP2-4.5. The best estimate of global surface temperature for mid-term, 2041-2060, is 2°C with a very likely range of 1.6 to 2.5 °C.

How are the models used?

1. Examine the table. Pick the surface temperature objective of the Earth for the years of interest and select a scenario.

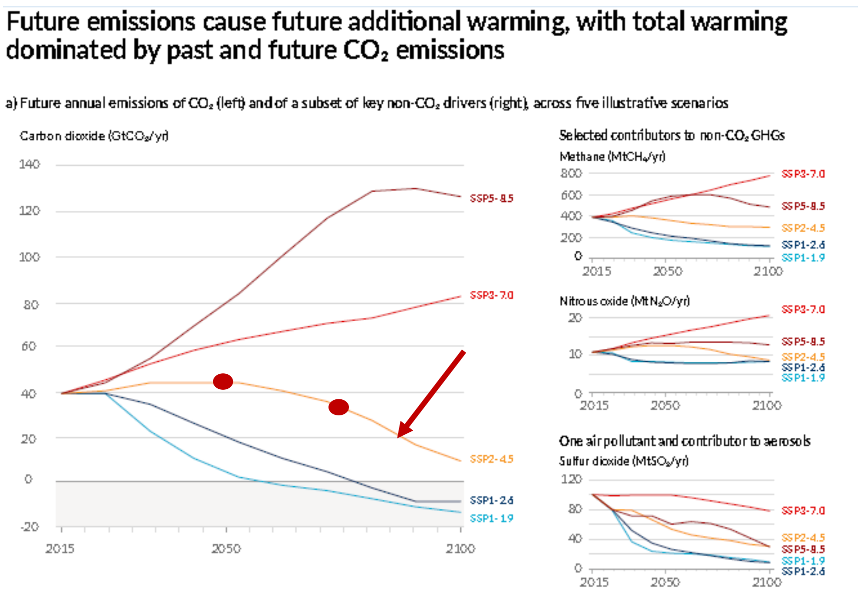
	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

or

2. Examine the IPCC Assessment Report AR6 WGII which provides the climate forecasts and their implications for life on Earth for each of the scenarios. There are many other reports which can help in our decision making and depending on resources custom scenarios can be considered (which will take a lot of effort).

then

3. Translate the scenario selected into an executable implementation program using graph by following the emission vs year curve of interest.



Example: SSP2-45 is selected.

Emission target for 2050 is 45GtCO$_2$/yr.

Emission target for 2075 is 35GtCO$_2$/yr.
And so on.

In a special meeting of the parties held in Paris in 2018 the IPCC has determined that a 1 to 2°C temperature increase from pre-industrial levels is the accepted target for 2100 to avoid the worst affects of global warming. This is known as the Paris Agreement: https://www.ipcc.ch/sr15/.

That is SSP1-1.9 – or close to it.

How do we do it?

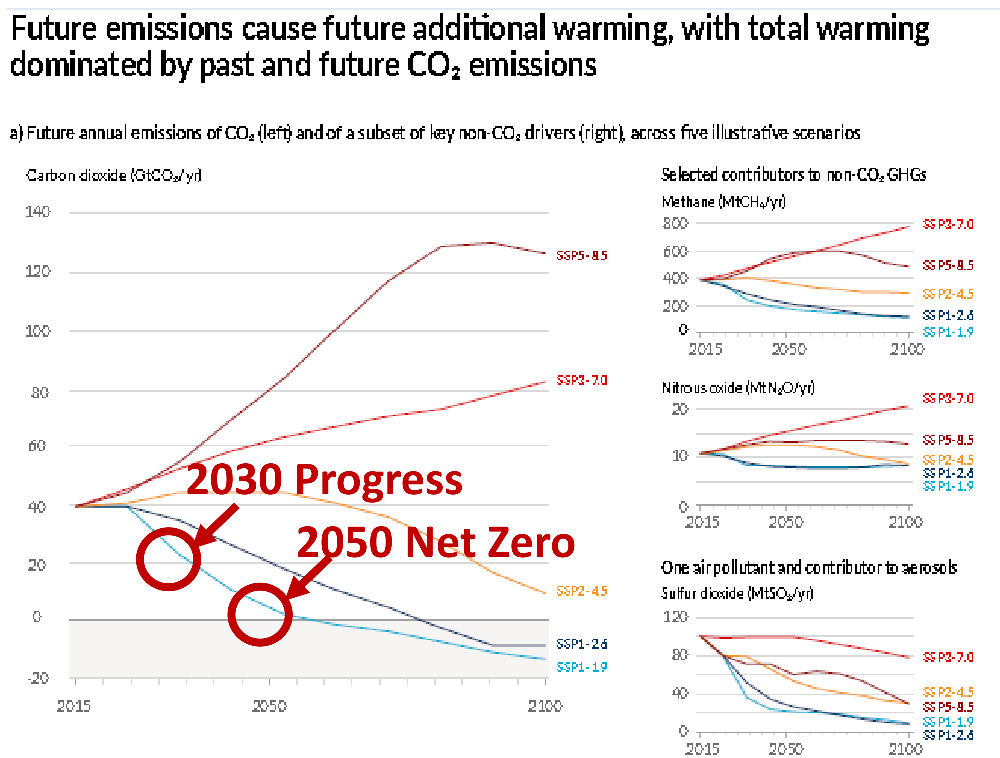
A huge challenge!

We’re talking about the need to create an executable GHG emissions implementation program on a Global Scale.

The GHG emissions management program that makes this feasible was endorsed in the Paris Agreement.

It is named ‘Net Zero’.

Net zero means that by year 2050 either no GHG's are emitted or GHG's that are emitted are offset by actions such as tree planting (a tree absorbs 25 kg of CO2/year). (GHG emissions – offset actions = 0 increase)



If the net zero emission target for 2050 is met, the global temperature is not expected to increase past 1.5 degrees C by 2100. (Similar to SSP1-1.9.)

Each nation determines how they will achieve this objective in what are called 'Nationally Determined Contributions' or NDC's. The NDC's, the manner with which they are to be achieved, and the progress being made to achieve the NDC are communicated to the UNFCC, https://unfccc.int/process-and-meetings/the-paris-agreement . These will be reported in 2024.

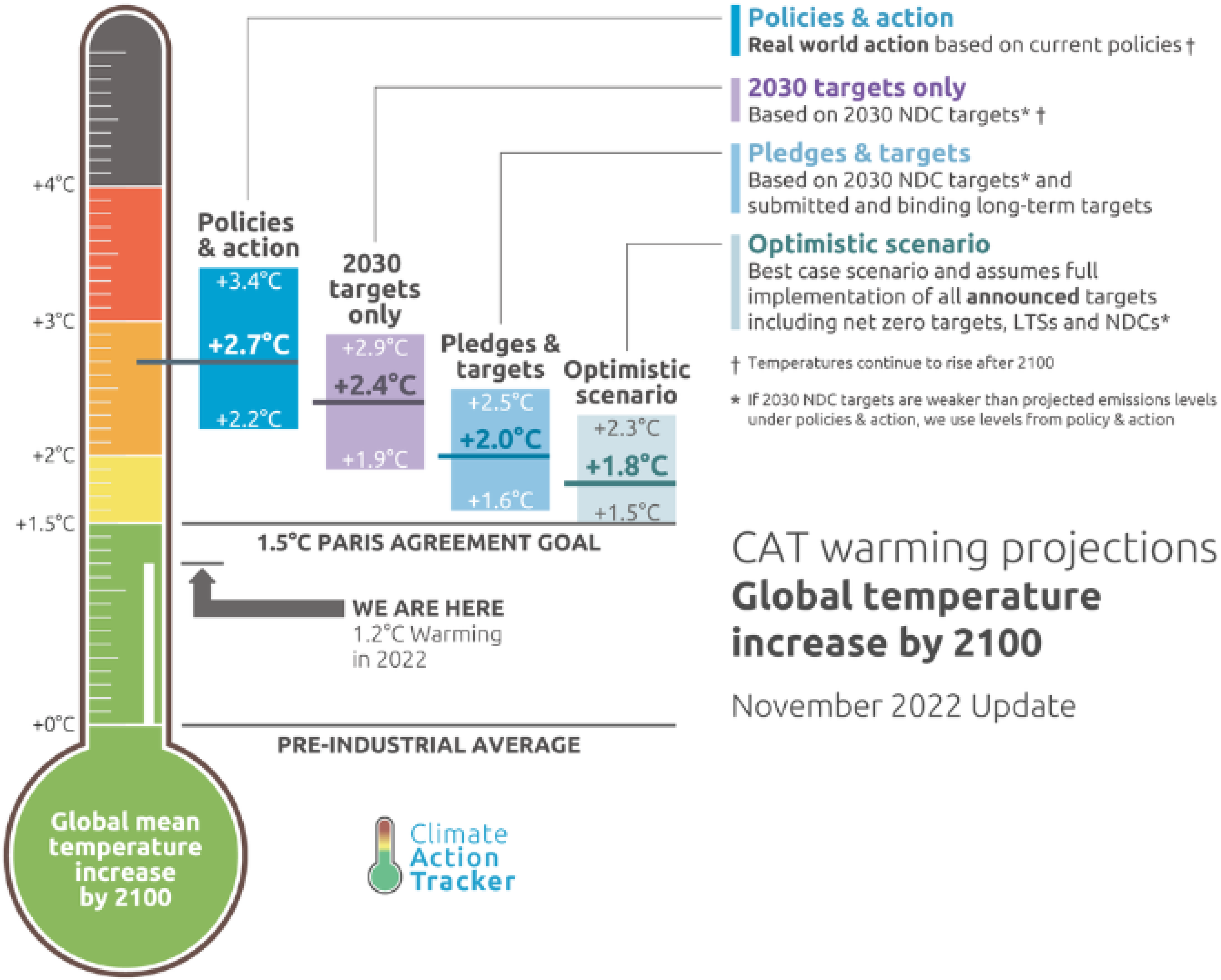
Canada's 'Net Zero Program by 2050' may be found at https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050.html

The UNFCC cautions that commitment to Net Zero must be followed by credible action.
(https://www.un.org/en/climatechange/net-zero-coalition?gclid=Cj0KCQiApb2bBhDYARIsAChHC9vsJ-ywo1MHPHsG7TlRcnXM-HJRuxRiZlFcqCohGwRnagKnGxWSBXoaAu-2EALw_wcB)

At this time the 'action' appears insufficient and if the 'inaction' persists the world is headed to temperature of

2.7 to 2.9°C in 2100.

Climate Action Tracker: https://climateactiontracker.org/global/cat-thermometer/



MOST IMPORTANT

It is important to recognize that we live in a global community linked by climate and economy. Even if the local effects of climate change do not appear significant, negative impacts somewhere else in the world may result in serious domino effects that might cause local hardship.

(It is very clear from recent experiences with the COVID 19 pandemic and the Russian invasion of the Ukraine that the entire world experiences the negative effects - supply chain confusion, food shortages, loss of energy supply, travel disruption, business disruption, inflation, recession, uncontrolled migration.)

The message: global warming and climate change anywhere on Earth is a threat to everyone on Earth.

Recap:

1. **Climate change was discovered – not invented – not a conspiracy.**
2. **Curiosity based science determined the physics behind the greenhouse effect and the role of greenhouse gases – carbon dioxide in particular.**
3. **The concentration of carbon dioxide in the atmosphere and global temperature are steadily increasing to levels not seen for over 2000 years – not business as usual.**
4. **Climate models have been developed that are able to predict future climate change occurring as a result of natural and human caused GHG emissions to the atmosphere.**
5. **Climate change attributable to human activities is having a very significant negative impact on Earth's physical environment and all life on Earth – sixth mass extinction.**
6. **Climate models have identified needs for human adaptation.**
7. **Climate models have enabled identification of mitigation strategies to avoid the worst impacts of climate change – e. g. development and use of renewable energy and other energy sources that do not emit GHG's.**

The 'Science of Climate Change' is important!
Achieving Net Zero GHG emissions by 2050, on a global scale, is essential!

Thank you.

Dr. David H. Manz, P. Eng., AOE, FCAE

https://manzwaterinfo.ca/climate-change

Climate Tipping Points, Domino Effects and Knock On Effects
What happens if we ignore global warming?

'Tipping point' is a metaphor that identifies a process where an otherwise small change in an input, that would normally have little effect on an outcome, results in a disproportionate response. A familiar example is 'the straw that broke the camel's back'. (e. g. A small change in temperature ultimately results in complete loss of habitat and the extinction of a plant or animal – one degree too high.)

'A domino effect' occurs when one process triggers another. (e. g. Climate change causes drought which results in loss of crops and water and food for livestock which results in starvation and loss of livelihood which results in mass migration.)

'Knock-on' effects can result in an additional increase to the input that originally caused the warming in the first place. The apparently amplified input can result in even greater consequences further strengthening the magnitude of the input. The phrase, 'out of control' comes to mind. (e. g. Global warming causes sea ice to melt resulting in more open water – more solar energy absorbed – increase in warming and higher temperatures – sea ice melts more rapidly. Another example is the thawing of permafrost which then releases methane which then increases rate of global warming.)

Tipping Points

If global warming exceeds 1.5 °C by 2100, a few of the tipping points that are expected to be reached include:

1. **Collapse of the Greenland ice sheet (resulting in substantial increase in sea level)**
2. **Collapse of the West Antarctic ice sheet (resulting in substantial increase in sea level),**
3. **Die off of tropical coral reefs, (significant loss of biodiversity) and**
4. **Abrupt thaw of the boreal permafrost.**

All bad!

References of interest are:

1. https://www.pnas.org/content/105/6/1786
2. https://en.wikipedia.org/wiki/Tipping_points_in_the_climate_system#Cascading_tipping_points
3. https://www.science.org/doi/10.1126/science.abn7950
4. https://phys.org/news/2022-09-multiple-climate-escalates-15c-global.html
5. https://phys.org/news/2021-06-elements-destabilize-climate-domino-effects.html

Runaway' global warming

'Runaway' global warming occurs when global warming becomes beyond our control. 'Hothouse Earth' would result.

(https://www.climateemergencyinstitute.com/runaway , https://www.pnas.org/doi/10.1073/pnas.1810141115 and https://en.wikipedia.org/wiki/Runaway_greenhouse_effect#:~:text=A%20runaway%20greenhouse%20effect%20occurs,liquid%20water%20on%20its%20surface.)

Mass extinction events would occur.

Carbon Trust November 2023: https://www.carbontrust.com/news-and-insights/insights/the-15c-challenge-how-close-are-we-to-overshooting-triggering-critical-climate-tipping-points-and-needing-to-go-beyond-net-zero

Key takeaways

- 1.5C global warming is not a cut off between safe and dangerous; it is a marker beyond which climate change impacts become unacceptably severe, which makes it a useful target.
- Human activity is undoubtedly responsible for the 1.2C global warming over the past 100 years, which is already intensifying extreme weather events.
- To have any chance of limiting warming to below 1.5C we have to bring emissions to zero or Net Zero by the middle of the century at the latest.
- At current levels of global emissions, we risk reaching 1.5C in the next decade.
- Phasing out fossil fuels is essential to limit warming to 1.5C.
- Carbon removal technologies will be necessary to reach Net Zero and can help bring temperatures back down if we overshoot 1.5. However, this becomes more difficult the higher the warming and the longer we stay above 1.5, and many of these technologies are not yet proven at scale.
- Protecting natural carbon sinks like forests and oceans is essential for human health and limiting global warming.
- At COP28, countries must make stronger commitments to reducing emissions urgently; developed countries must also provide support to help climate-vulnerable countries avoid and adapt to climate change.